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Neutron dosimetry measurement

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Abstract : This work has been carried out to find a technique for measuring the fast neutron fluences by using gelatin doped with $MnCl_2H_2O$. The change of the ac conductivity, the real part of the dielectric constant (ε'), the imagenary part of the dielectric constant (ε'') and the tangent of the loss angle (tan δ) were measured for both pure and Mn-gelatin samples. These measurements have been carried out under the influence of an electric field of frequency 10 kHz and at different values of temperature before and after exposing to fast neutrons of fluences 7.6×10^6 to 0.5×10^9 n/c m^2.

The obtained results of ε' and ε'' *versus* the neutron fluences, at the peak value and constant frequency of 10 kHz, showed a good proportionality through the investigated range of fast neutron fluence. This proportionality enables one to conclude that Mn-gelatin film can be used as a detector for fast neutron through this studied range.

Keywords : Fast neutron fluences, Mn-gelatin film

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1. Introduction

Recent researchers have focussed their studies on new materials composed of biopolymers for numerous applications especially in clinical practices [1,2]. Gelatin, as a biopolymer material, is one of the most important categories for such applications [3]. It is a synthetic biopolymer derived from collagen by hydrolysis action [4]. In addition, it is an organic nitrogeous collidal protein, which lacks to some amino acids, as tryptophane. Also, gelatin can be classified into edible, technical, photographic and pharmaceutical gelatin [3,5].

In contrast to collagen, gelatin contains free α-amino groups and C-terminal amino acids [4]. Its glass transition temperature (Tg) depends strongly on even small water content. For example, a shift in glass to rubber transition temperature can amount to 5–7 degree through 1% changing of the water content. Moreover, the bounded water is an

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intrinsic element of ordered structure, acts as a natural plasticizer, lowering the Tg, while free water in gelatin forms a rigid ice matrix inhibiting Tg [6].

The denaturation process (by heating or irradiation) destroys the unique native structure of biopolymer after which it can be considered as statistical copolymers composed of chains with different combinations of the residue amino acids. Also, rupturing of chemical bonds which yields free ions from the broken ones, as well as displacement of electrons and atoms, can be obtained through the interaction of fast neutrons with polymers. Consequently, the energetic free radical may react with each other or with the surrounding medium. Thus a change in the chemical structure and physical properties of the material can be observed [7]. For biopolymer, carbonyl, amid and sulphedyrial groups are produced as a result of such interaction [8].

Damjanouic *et al* [9] studied the dielectric properties of triglycerol-gelatin films. They found that both the dielectric constant ε' and the loss tangent (tan δ) strongly dispersive near room temperature. The dielectric loss exhibits two peaks in the range from –50 up to 50°C. Therefore, they suggested the presence of two dissipation mechanisms, one is dominate at higher temperature (α-peak) while the other (β-peak) is at lower values.

In the present work, the electrical conductivity, temperature stability as well as the dielectric properties for the investigated sample before and after irradiation for different fast neutron fluences (7.6×10^5 up to 0.5×10^9 n/cm^2) have been studied at different temperatures (~ –15 up to 170°C).

2. Experimental

A. Sample preparation :

Gelatin used in this work was analar grade in a powdered form (B.D.H.). 0.05 part by weight of $MnCl_2$. H_2O with gelatin was used. Both of them were dissolved in triply distilled water at 50°C after which their solution were mixed together. The mixture was casted in petri-dish of diameter 10 cm. The petri-dish was placed on a levelled plate in the furnace at the same temperature of preparation for 24 hours to remove any residual solvent that might be present and a complete drying was checked by weighing the petri-dish with the sample before and after preparation. The sample thickness was found to be 0.09 mm.

B. Experimental techniques :

The electrical properties were studied for the Mn-gelatin samples before and after irradiation by fast neutron fluences (7.6×10^5 to 0.5×10^9 n/cm^2). Both surfaces of the sample were coated with silver paste using a mask and checked for good contact after which the sample was inserted in a holder inside the vacuum cryostat with a thermocouple junction in contact with it to get temperature with accuracy better than ~ 1°C.

The dielectric constants and dielectric loss factor ε' and ε'' respectively are related to the complex dielectric constant ε^* :

$$\varepsilon^* = \varepsilon' - i\varepsilon'',$$

in which the value of ε'' can be calculated from the function :

$$\tan\delta = \varepsilon'' / \varepsilon',$$

where $\tan\delta$ is the dielectric loss.

These dielectric measurements were carried out on RLC bridge Model SR 720 (U.S.A.). The experimental data were obtained at different temperatures for Mn-gelatin film before and after irradiation at a constant value a frequency (10 kHz). Also, fading effect was taken into consideration by measuring the dielectric constant at varying times after irradiation (1 to 15 days). The neutron source that used in the present work was fifty μg ^{252}Cf at Biophysics Department, Cairo University. This source was manufactured by the radiochemical center, Amersham, England. The present yield of the neutron source (A) was 4×10^6 n/sec. Its fluence was calculated from the relation $\phi = At/4\pi d^2$., where d and t are the sample to source distance (in cm) and the exposure time (in sec), respectively.

3. Results and discussion

Group of Figures (1–3) indicate the effect of different fast neutron fluences (7.6×10^5, 7.6×10^6, 3.05×10^7, 1.45×10^8 and 0.5×10^9 n/cm^2) on the ε', ε'' and ac conductivity (ln σ) at constant frequency (10 kHz) as a function of temperature. Previously, it was found that many polymers show cross-linking formation during radiation degradation [10,11]. Gelatin as one of such polymers, exhibits cross-linking at lower doses of fast neutrons and degradation at higher ones. The behaviour of ε' and ε'', Figures (1, 2) respectively, show a

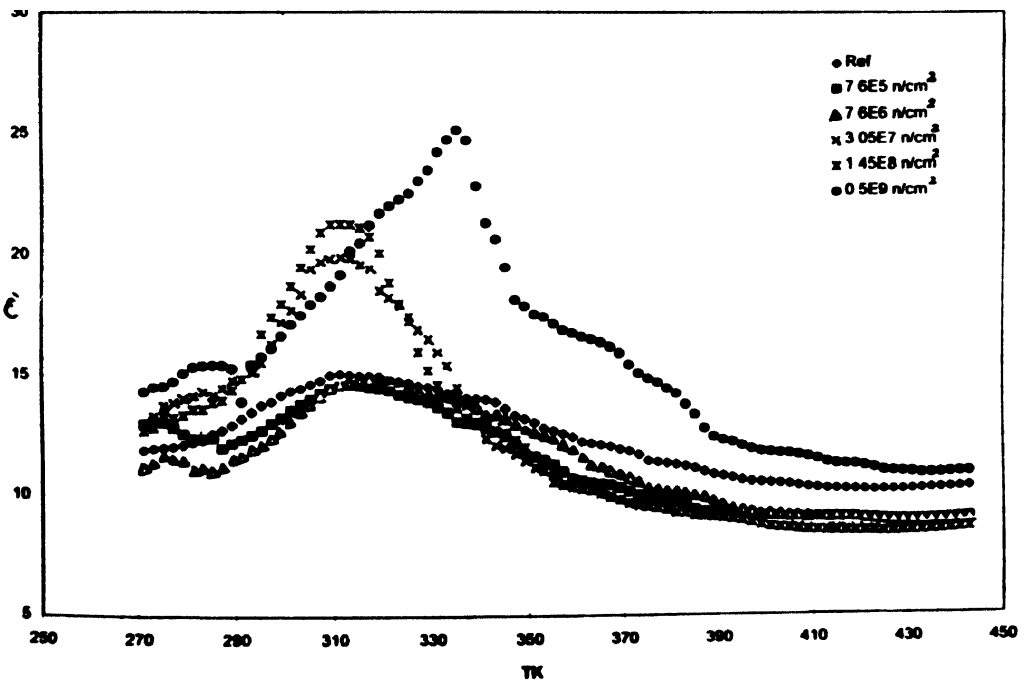

Figure 1. The variation of ε' with temperature at different fast neutron fluences at constant frequency.

smooth increasing with fast neutron doses. Thus, Mn-gelatin exhibits only scission of the main chain, which produces a free radicals or ions leading to an increase of ε' and ε''. This

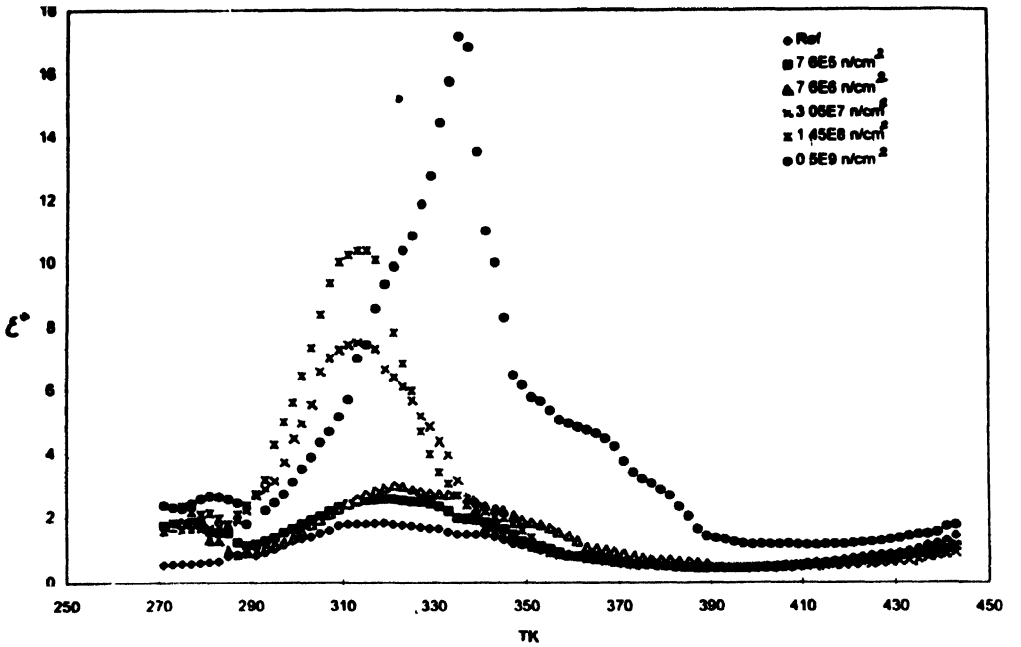

Figure 2. The variation of ε'' with temperature at different fast neutron fluences at constant frequency.

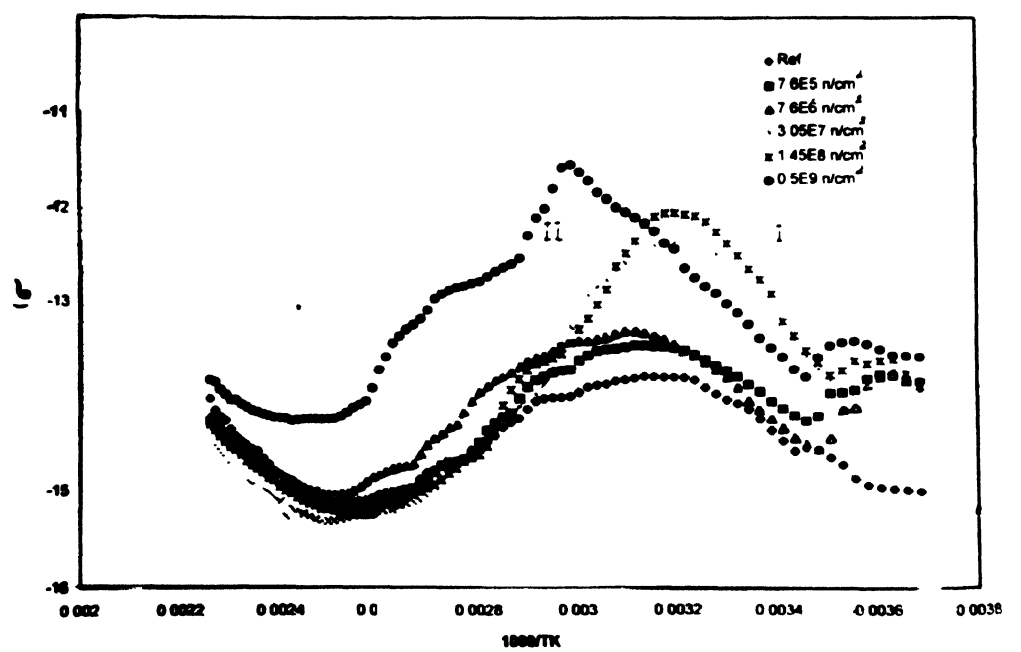

Figure 3. The variation of ac conductivity with temperature at different fast neutron fluences at constant frequency.

may be due to the rupturing of Mn-gelatin bonds and the branching side groups of the residue of amino acids. Furthermore, oxygen of the air may react with the cross-linking at low doses, forming a peroxidic structures, thus oxidative degradation of the main chain may be occurred. On the other hand, the possibility of degradation of Mn-gelatin will be increased with increasing doses as well as the presence of oxygen.

At the same time, the data in Figure 1 reveals a peak value around the glass transition temperature. The shift in the peak position is not clear except at 0.5×10^9 n/cm^2. This shift may be due to the motion of the main chain as well as the dipoles can not follow the field variation that accompanied the applied frequency. In addition, the size of the produced free radicals at higher doses becomes too large enough, so it needs more thermal energy to be aligned in the field direction.

Moreover, from a closer look to Figure 1 one can find that the value of ε' for the unirradiated sample is greater than those of irradiated ones with 7.6×10^5 and 7.6×10^6 n/cm^2 at the peak position. This behaviour may be due to the increase of cross-linking and the decrease in the mobility of the degradiated radicals.

The ac conductivity for different fast neutron fluences is shown in Figure 3, which correlate ln σ *versus* 1000/T K. The values of activation energies before and after irradiation for region I and II are listed in Table 1. In region I, the thermal energy is not sufficient to move all free carriers to participate in conduction mechanisms, so the conductivity of the unirradiated Mn-gelatin sample is higher than that of the irradiated ones.

Table 1. The values of the activation energies in the low (EI) and high (EII) temperature regions respectively, before and after irradiation (at 10 kHz), where Ref refers to the unirradiated sample.

	10 kHz	
	EI	EII
Ref	0.218	0.4
7.6×10^5 n/cm^2	0.291	0.364
7.6×10^6 n/cm^2	0.345	0.327
3.05×10^7 n/cm^2	0 446	0 382
1.45×10^8 n/cm^2	0.582	0 364
0.5×10^9 n/cm^2	0 364	0.273

But in region II, the situation is different, where the conductivity of the irradiated samples becomes greater. This increasing in the conductivity for irradiated samples (region II) may be attributed to the rupturing of hydrogen bonds and liberating of single and multiple hydrogen bonded water, which is attached to polar resídues of amino acids [12]. Also, the interaction of fast neutron with the biomatter may create a highly energetic proton recoils, carbon and oxygen nuclei resulting from neutron elastic scattering with hydrogen, carbon

and oxygen atoms forming the backbone of Mn-gelatin [13] film. All these particles will immigrate, under the influence of increasing thermal energy in the network structure, causing further damages along their trials. This leads to formation of free radicals and fractured molecules till they are trapped or recombined again randomly under the accelerating thermal energy, from the surrounding. Thus, new molecules with different configurations will result.

Since the aim of the present work was to investigate the possibility of using Mn-gelatin film as a neutron dosimeter, therefore it was necessary to indicate the variation

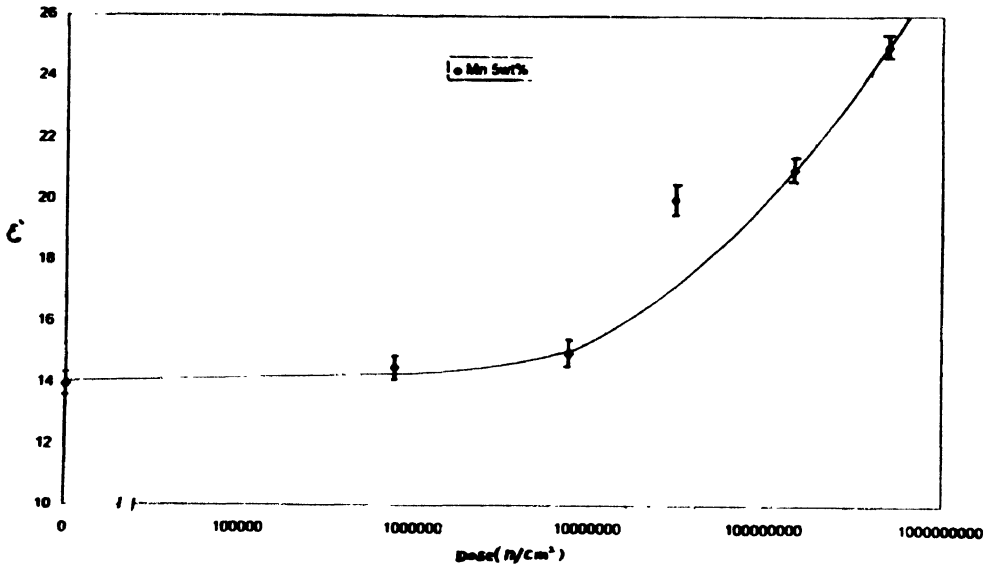

Figure 4. The variation of ε' with fast neutron fluences at constant frequency.

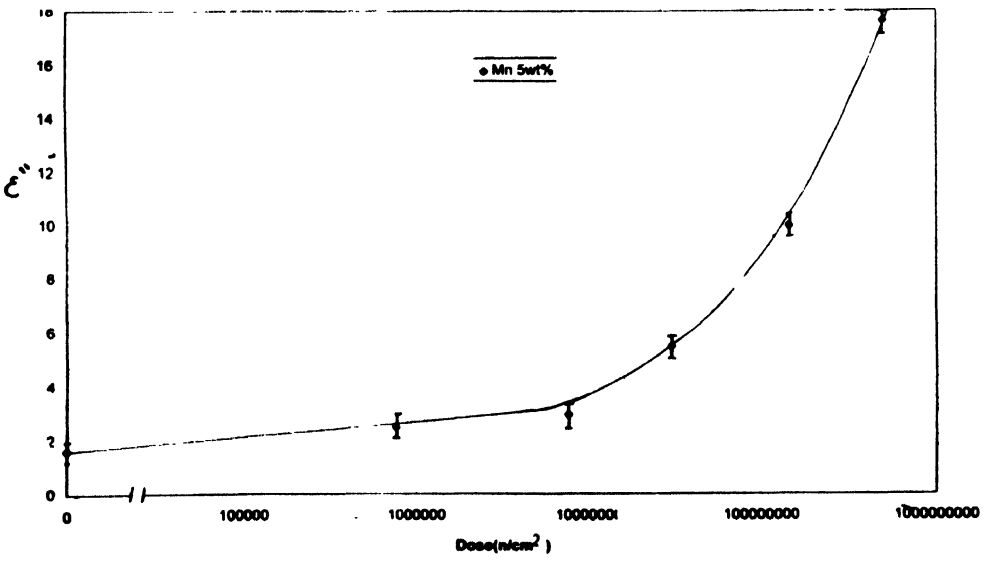

Figure 5. The variation of ε'' with fast neutron fluences at constant frequency.

of the electrical properties with fast neutron fluences. This variation can be shown from Figures 4 and 5, which indicate the relation between ε' and ε'' at the peak value and the corresponding values of fast neutron fluence. From these figures, one can observe immediately the proportionality between ε' and ε'' and the different values of fast neutron fluences. This proportionality has been achieved at lower, intermediate and higher values for neutron fluence. Moreover, the fading effect was calculated during two weeks after irradiation and was found to be ~ 6%, which means that ε' and ε'' are approximately stable during the experimental measurements.

From the above studies, it becomes clear that Mn-gelatin film can be used as a detector to measure the fast neutron fluences in this wide range up to 10^9 n/cm^2. Thus, the usage of Mn-gelatin film can be considered as a new technique for measuring fast neutron fluences. Therefore, it becomes of great importance to carry out more experimental studies in order to support this new measuring technique for other types of radiations.

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